



## Development and calibration of an engineering model for simulation of wake velocity deficits

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# Development and calibration of an engineering model for simulation of wake velocity deficits

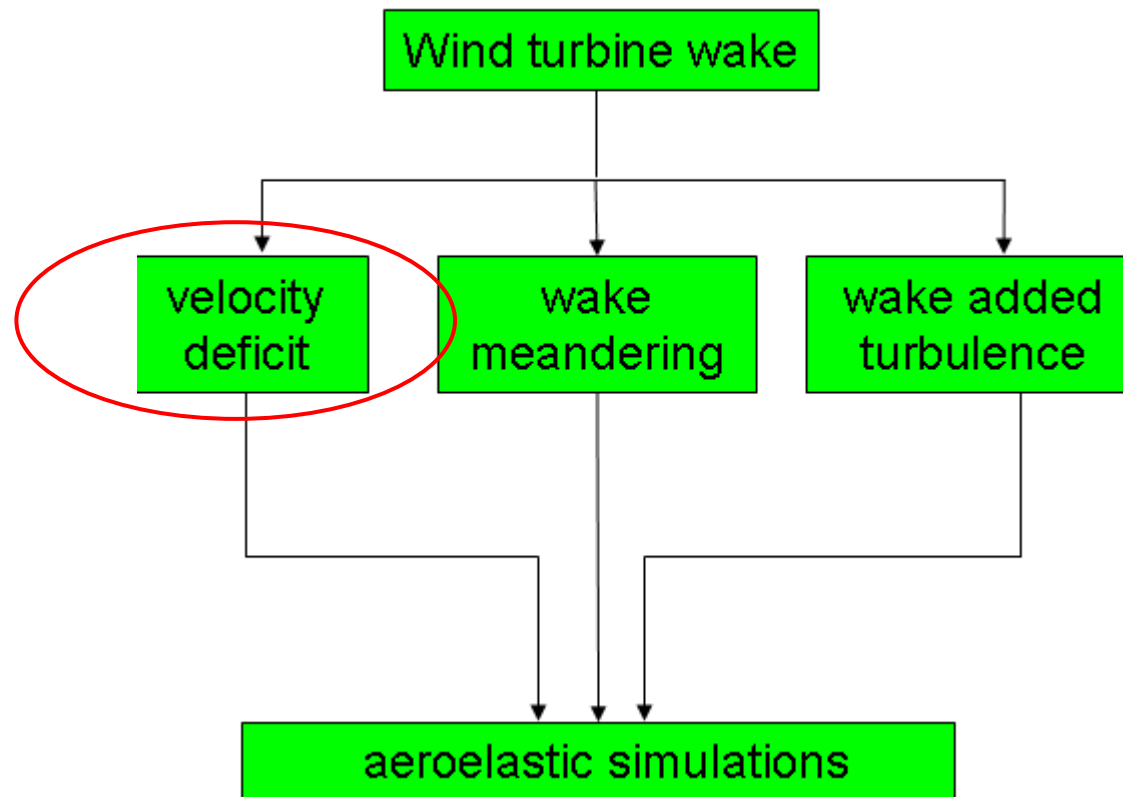


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# Background – The Dynamic Wake Meandering (DWM) Model

## DWM model



# Model description – DWM model

## Three model parts

- 1) *Wake deficit generation and development*
- 2) *Wake meandering*
- 3) *Generation of wake added turbulence*

and

**fully integrated in the aeroelastic code HAWC2**  
- just specify positions of wake generating turbines -

Aagaard Madsen, H.; Larsen, G.C.; Larsen, T.J.; Mikkelsen, R.; Troldborg, N., Wake deficit-and turbulence simulated with two models compared with inflow measurements on a 2MW turbine in wake conditions. In: Scientific proceedings. 2008 European Wind Energy Conference and Exhibition, Brussels (BE), 31 Mar - 3 Apr 2008. (2008) p. 48-53

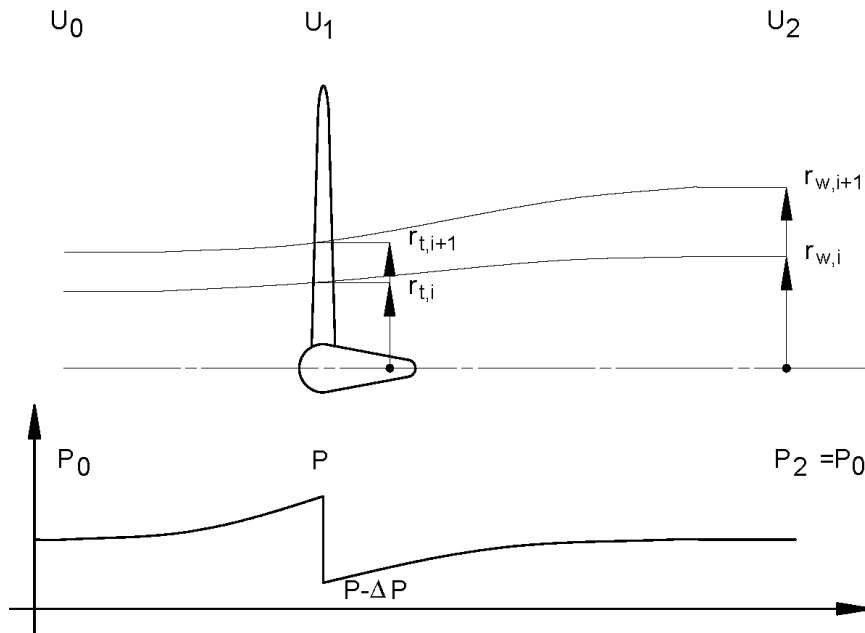
# Approach for generation of initial velocity deficit and its development downstream

1. Generation of initial deficit from BEM induction in far wake combined with continuity in stream tubes
2. A boundary layer equation model (BLE) is used for developing initial velocity profiles as function of downstream position under influence of self generated turbulence viscosity and from contribution from ambient turbulence

# Model description

## 1) Generation of initial velocity deficit

### Derived from the BEM induction



initial velocity  $u_2(r_{w,i})$

$$r_{w,i+1} = \sqrt{\frac{1-a_i}{1-2a_i} (r_{t,i+1}^2 - r_{t,i}^2) + r_{w,i}^2}$$

# Model description

## 2) Velocity deficit development

Based on a numerical implementation of the thin shear layer approximation of the Navier-Stokes equations – axis-symmetric - with initial conditions obtained from BEM

$$U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial r} = \left( \frac{v_T}{r} \right) \frac{\partial}{\partial r} \left( r \frac{\partial U}{\partial r} \right)$$

$$v_T = k_2 b (U_0 - U_c) + v_{TA}$$

$$v_{TA} = k_1 T i$$

$$\frac{1}{r} \frac{\partial}{\partial r} (r V) + \frac{\partial U}{\partial x} = 0$$

# Model description

## - influence of ambient turbulence

### Ainsley

$$\varepsilon_{tot} = k_2 b(U_0 - U_c) + \frac{K}{\ln(z_H / z_0)}$$

can be rewritten to:

$$\varepsilon_{tot} = k_2 b(U_0 - U_c) + \frac{TI(z)}{\alpha}$$

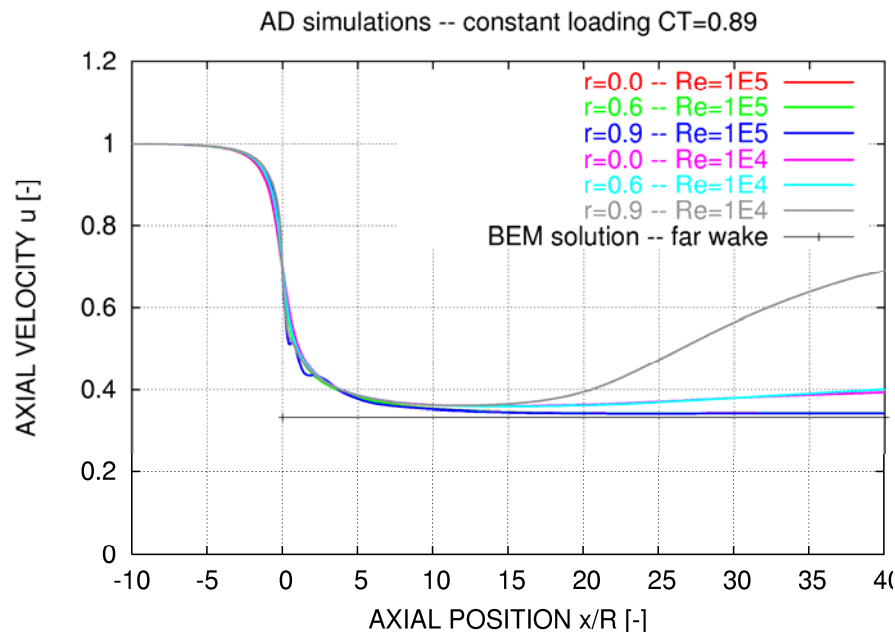
with  $\alpha = 2.4$



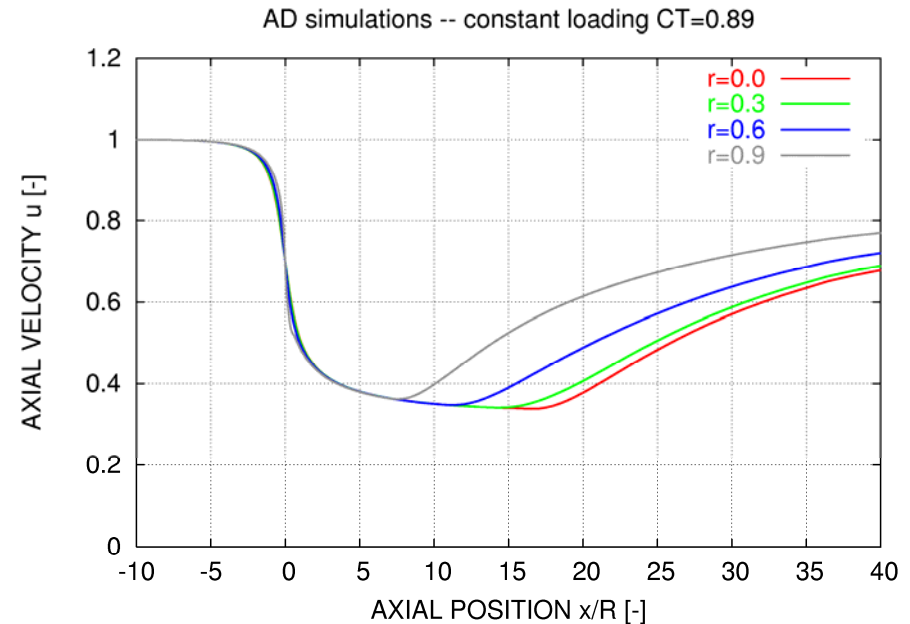
# Actuator disc (AD) simulations used for calibration of the BLE model

## LAMINAR FLOW

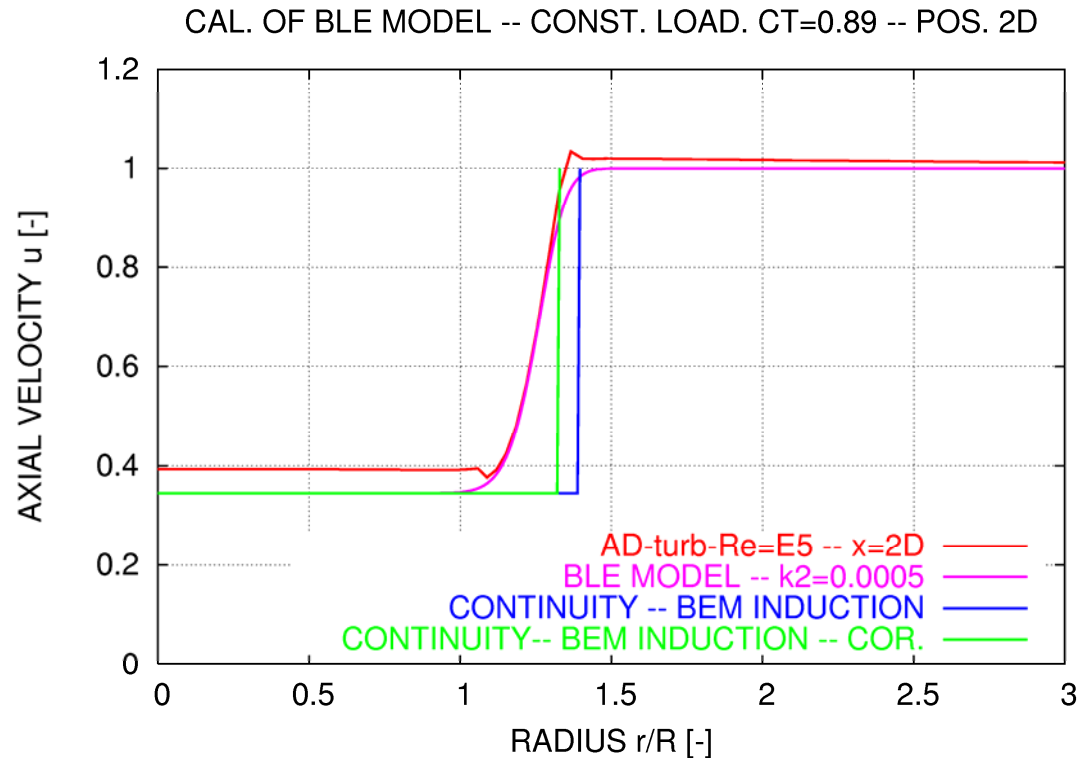
- influence of Re. no.



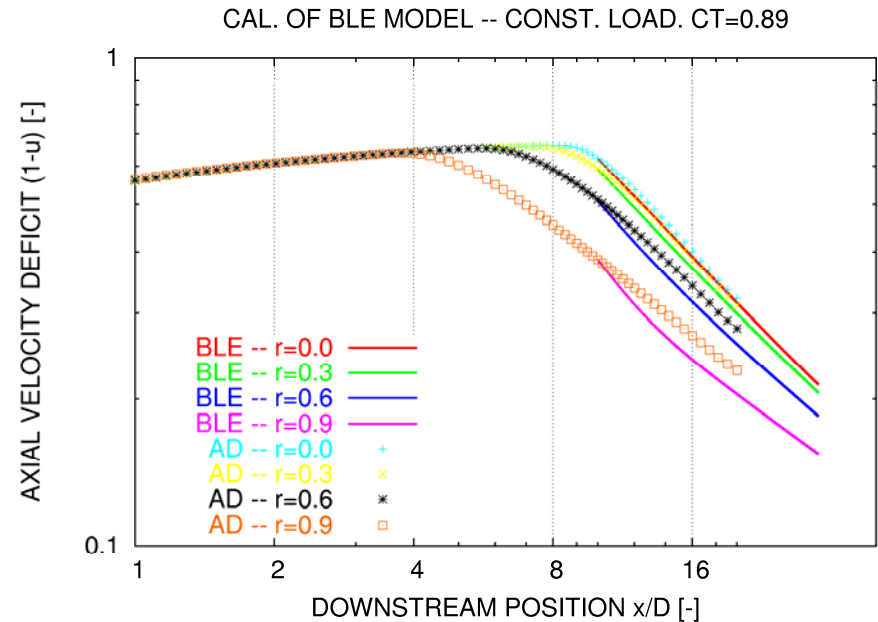
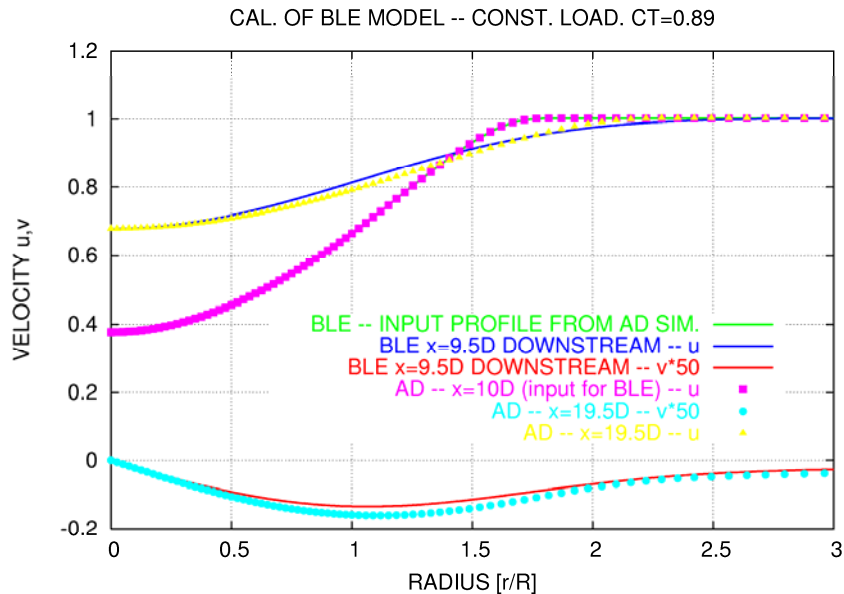
## TURBULENT FLOW



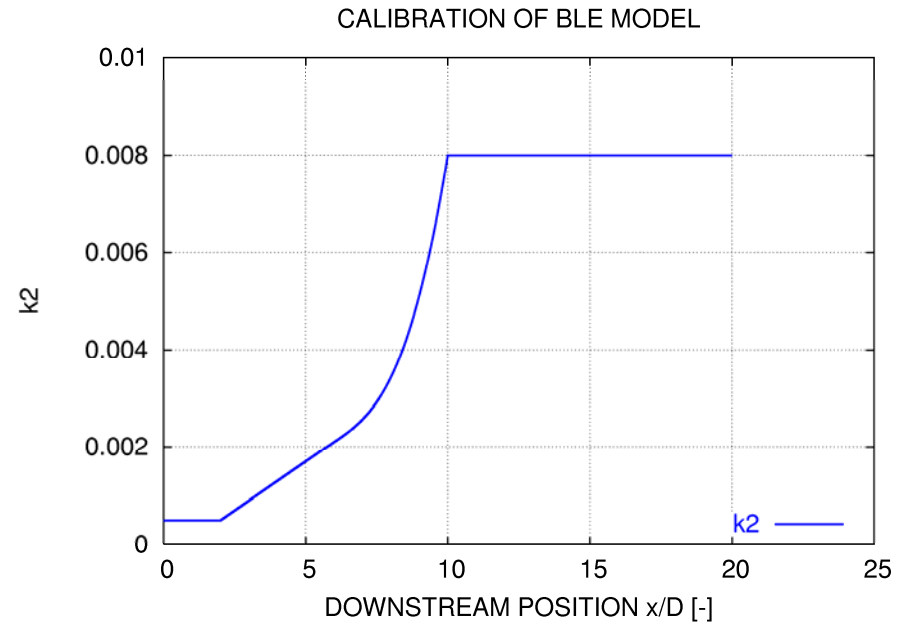
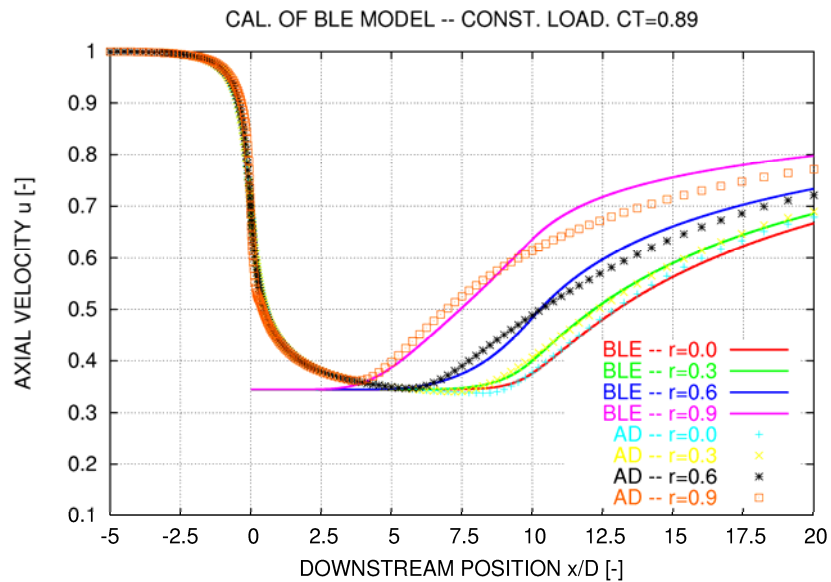
# Calibration of initial deficit and $k_2$ in the near wake region – 2D



# Calibration of $k_2$ in the far wake from 10D downstream

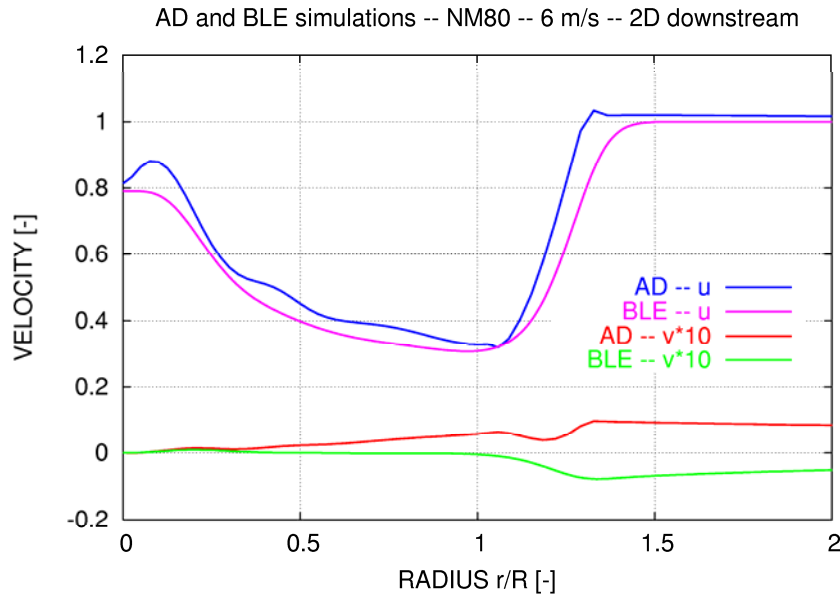


# Calibration of $k_2$ in the intermediate wake region

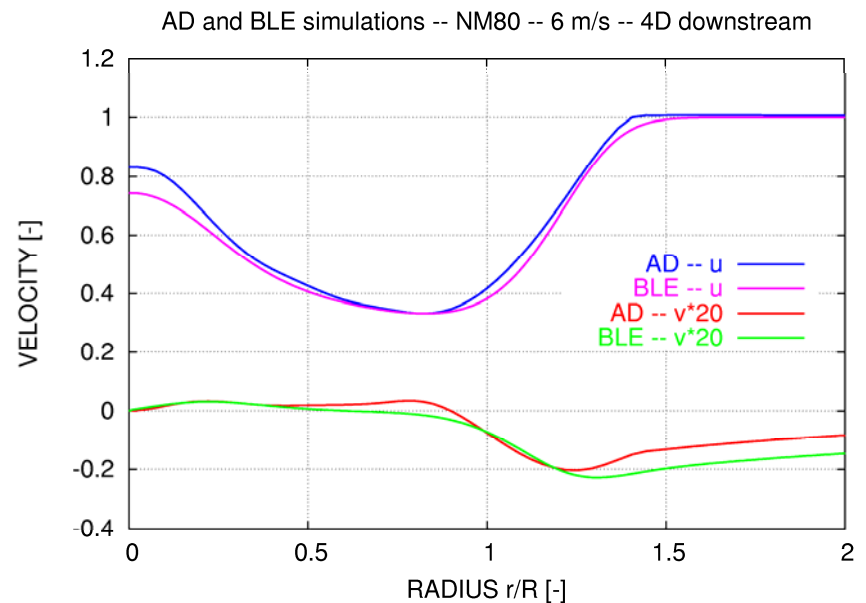


# Use of the BLE model on the NM80 rotor. Comparison of the BLE model with AD results

## 2D downstream

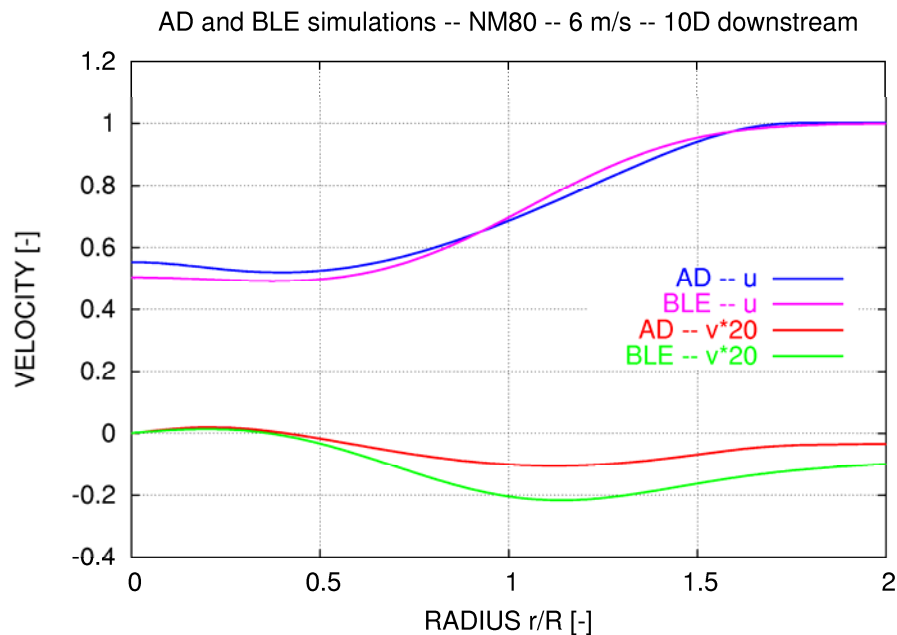


## 4D downstream

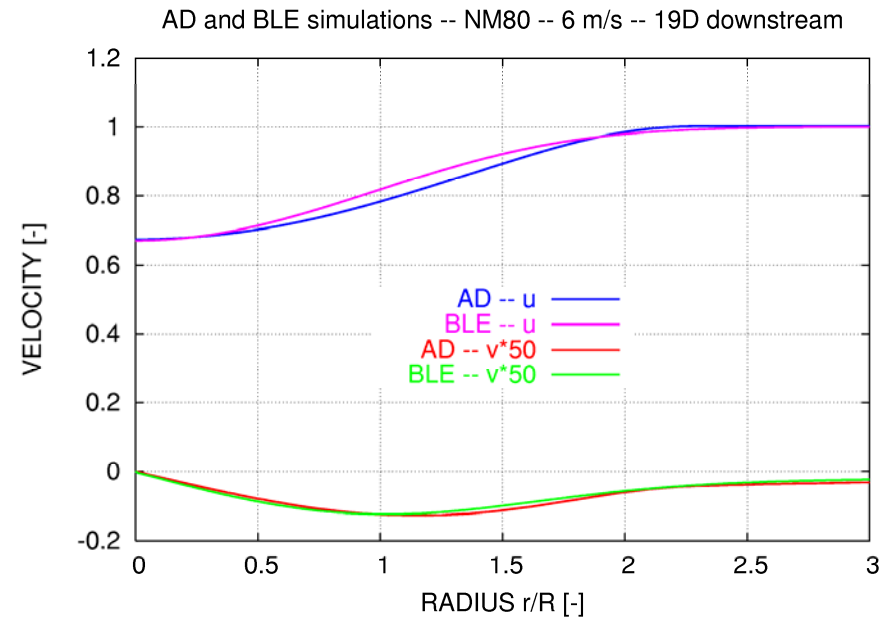


# Use of the BLE model on the NM80 rotor. Comparison of the BLE model with AD results

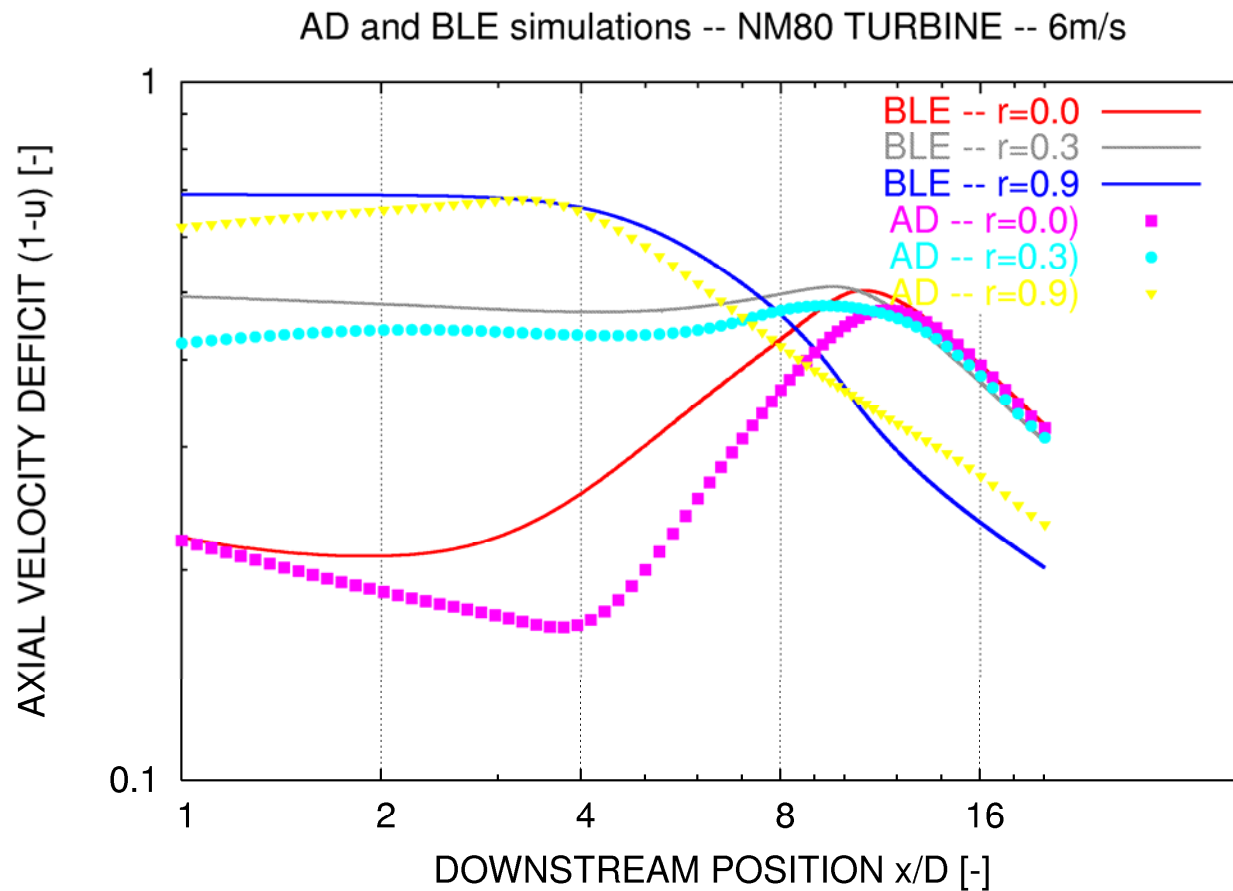
## 10D downstream



## 19D downstream



# Use of the BLE model on the NM80 rotor. Comparison of the BLE model with AD results



# Influence of ambient turbulence

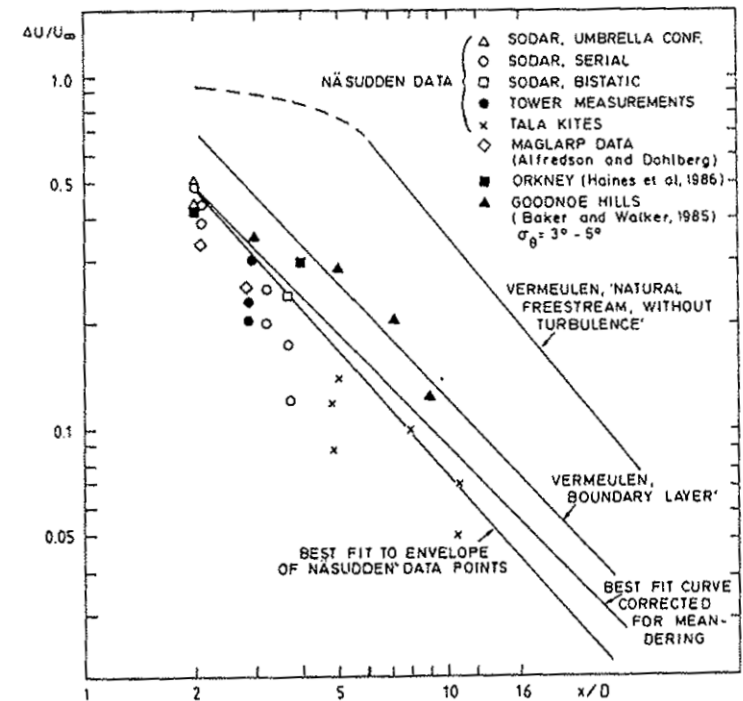
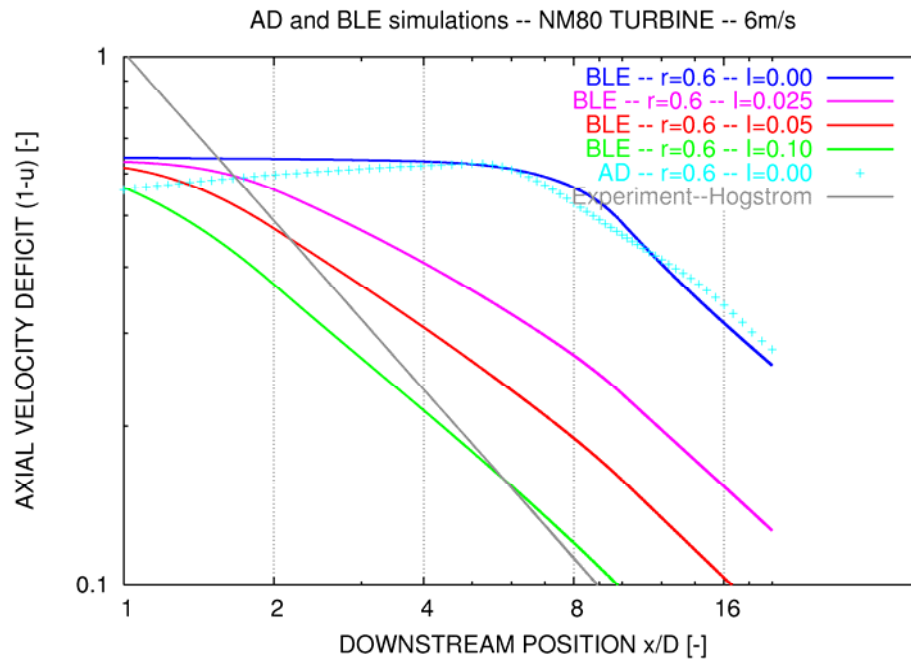
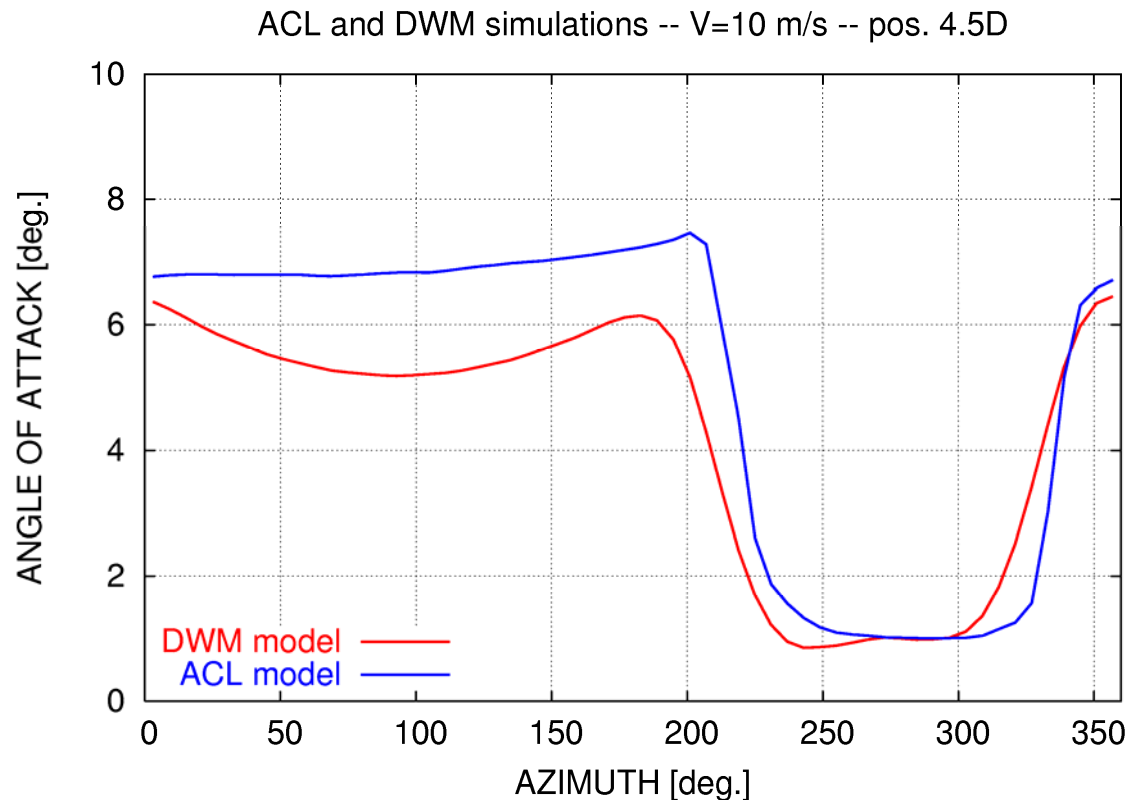


Fig. 9. Relative centre line velocity defect,  $(\Delta U/U_\infty)_0$  as a function of distance downwind from the Näsudden data compared with data from some other sources.

Högström et al. 1988

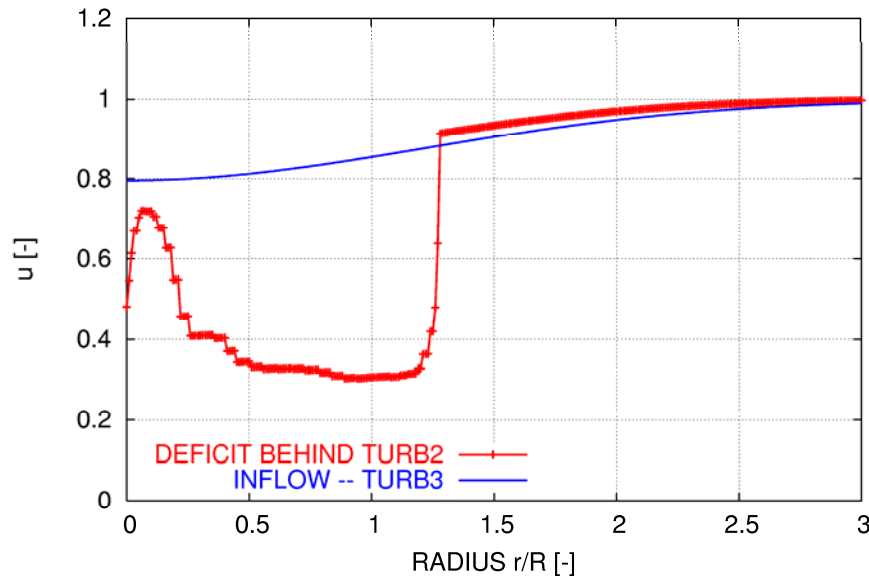


# Comparison with the ACL model – DTU MEK NM80 rotor at 10 m/s – no amb. turbulence

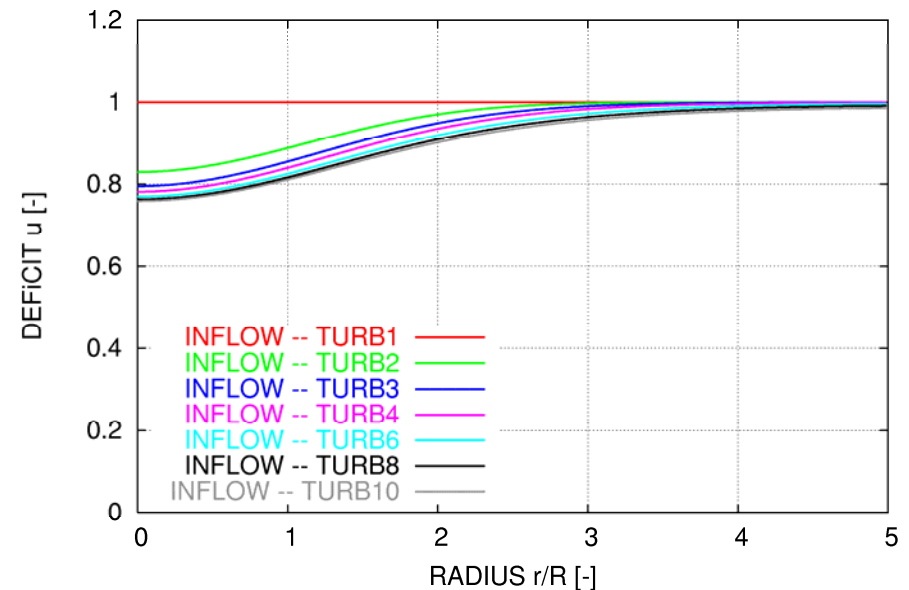


# Using the BLE model for computation of power losses of an array of turbines

COMPARISON OF DEFICITS -- SPACING 10D

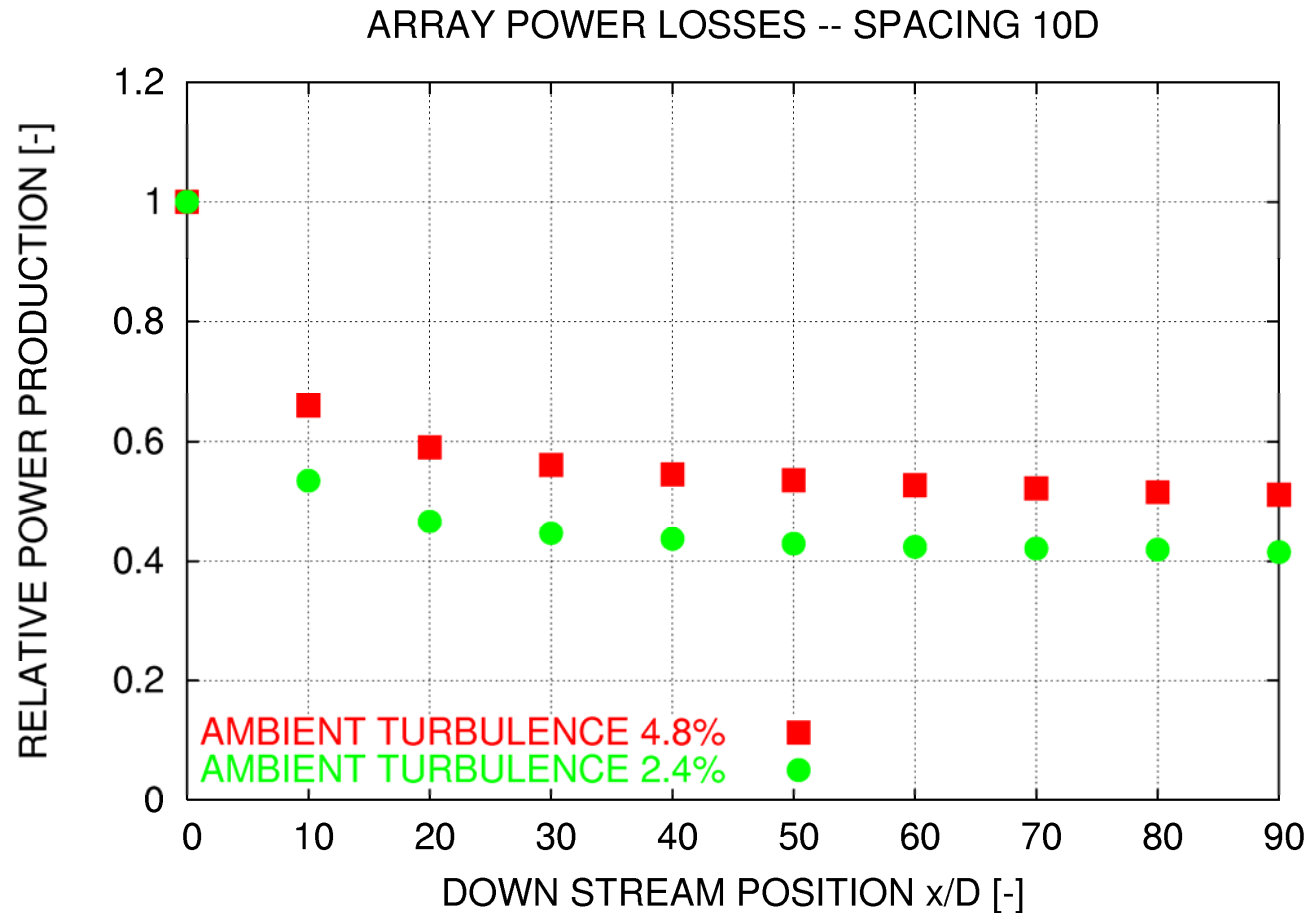


COMPARISON OF DEFICITS -- SPACING 10D

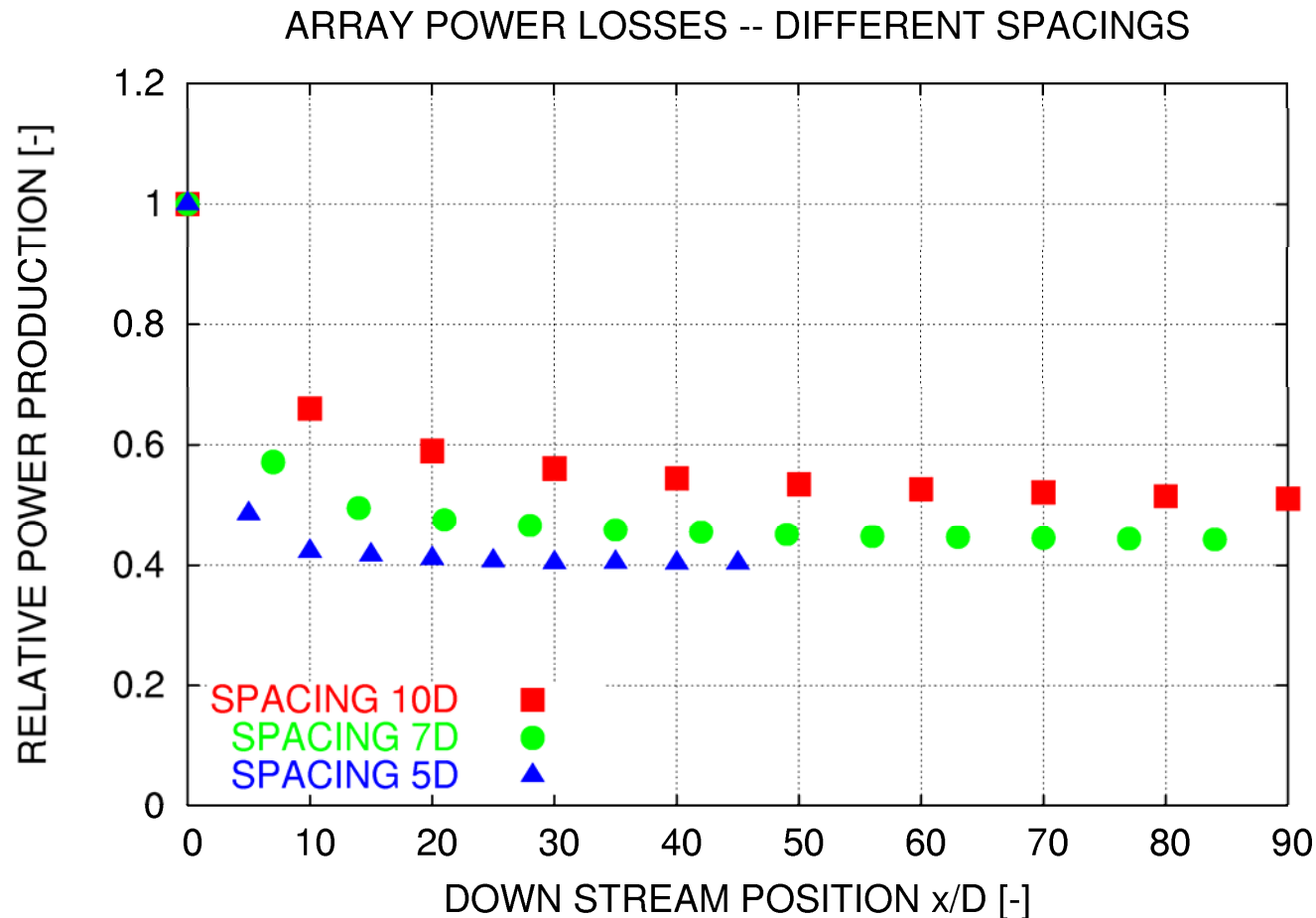


# Using the BLE model for computation of power losses of an array of turbines

-- NM80 rotor at 10 m/s --



# Using the BLE model for computation of power losses of an array of turbines -- NM80 rotor at 10 m/s – ambient turbulence 4.8%



# Conclusions and outlook

- an engineering model (BLE) has been developed for computation of the velocity deficit behind a turbine
- the influence of ambient turbulence is a key parameter for the development of the velocity deficit as function of downstream position
- the ambient turbulence is thus also one of the key parameters for wind turbine array losses
- further development of the axisymmetric BLE model to a quasi 3D model is investigated